

The effects of a stressed inshore urban reef on coral recruitment in Suva harbour, Fiji

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A relic inshore reef ecosystem adjacent to the Fijian capital of Suva and another remote inshore reef were monitored monthly from July 2014 to July 2015 for coral recruitment, sedimentation rates, coral cover, temperature and light intensity. Despite a major sewage spill in Suva Harbour in December 2014, the municipal inshore site, exposed to extreme environmental stress, recorded no significant differences in coral spat abundance (except for the family Poritidae) on artificial substrata compared to the remote inshore site. Total yearly spat abundance was 106 on municipal reef and 132 on remote reef while total annual sediment deposition was significantly higher in the municipal site (657.14 g.cm^{-2}), compared to the remote site (371.52 g.cm^{-2}). Total annual Particulate Organic Matter content in sediment was also significantly higher in the municipal site (107.51 g.cm^{-2}), compared to the remote site (43.37 g.cm^{-2}). Mean light intensity was significantly lower for the municipal site (69.81 lum/ft^2) compared to the remote site (239.26 lum/ft^2), with Photosynthetically Active Radiation also lower for the former ($800\text{-}1066.66 \text{ } \mu\text{mol m}^{-2} \text{ s}^{-1}$) compared to the latter ($3266.66\text{-}3600 \text{ } \mu\text{mol m}^{-2} \text{ s}^{-1}$). The lack of differences in coral spat recruitment rates suggests that settling larvae may be unable to distinguish between polluted and non-polluted sites probably as a consequence of interference with coral settlement cues arising from anthropogenic development.

Keywords: Coral recruitment, Coral diversity, Sedimentation, Pollution, Inshore

The reproductive capacity of a reef ecosystem is vital to its sustainability (Bauman et al., 2015). The viability of its community structure is largely reliant upon the coral reef communities being either self-seeding, where the coral larvae can be retained on a reef system through water flow patterns (Black et al., 1991), or dependent upon the transportation of larvae from adjacent reefs (Fisk and Harriott, 1990). The recruitment of coral juveniles is considered a major determinant of community structure in marine ecosystems and is recognised as a fundamentally important influence affecting the distribution and abundance of reef organisms (Babcock and Mundy, 1996, Harriott, 1992). The recruitment or re-establishment of coral functional groups characteristic to a particular locality is also considered vital to the resilience, maintenance, and recovery of coral reefs (Bellwood et al., 2004, Hughes et al., 2010, Bauman et al., 2015). Coral recruitment rate is affected by a multitude of factors, some of which include depth, orientation of the substratum, competition with other organisms, grazing, availability of suitable habitat, and larval dispersal capabilities (Harriott, 1992). Specific coral larval settlement cues involving reef acoustics, chemical-algal signals, reef surface parameters, and light are vital in influencing the orientation of coral planulae towards healthy reefs for settlement (Strader et al., 2015, Tebben et al., 2015, Vermeij et al., 2010). Major urban and industrial infrastructures may mask or distort acoustic cues through noise, disrupt and interfere with chemical signals through sediment and toxic pollutant influx, inhibit light availability through high turbidity, induce sediment smothering of settlement-cue-surfaces i.e. coralline algae, and mislead planulae larvae towards settling near developed coastal areas hosting high intensity artificial light stimuli (Codarin et al., 2009, Tebben et al., 2015, Davies et al., 2015, Leduc et al., 2004, Munday et al., 2009, Perez III et al., 2014, Slabbekoorn et al., 2010, Bauman et al., 2015).

Excessive sedimentation in coral reef ecosystems as a result of anthropogenic influences is also an important parameter which affects coral larval recruitment and is one of the most widespread contemporary, human-induced perturbations on coral reefs (Birkeland, 1977, Bak and Engel, 1979, Rogers et al., 1984, Birrell et al., 2005, Bauman et al., 2015). Heavy sedimentation in reef environments generally results in larger coral colonies through limited recruitment rates, settlement of corals on vertical surfaces as a response to high sediment rates, algal competition, and the inability of coral larvae to establish themselves in shifting sediment regimes (Birkeland, 1977, Rogers et al., 1984, Rogers, 1990). However, a

study conducted at a site in Yanuyanu-i-Sau at the Great Astrolabe Reef south of Viti-Levu, Fiji, revealed that high sedimentation rates in that area did not result in low coral recruitment rates (Quinn and Kojis, 2008). Typically, it is acknowledged that sedimentation significantly reduces the potential reproductive capacity of corals (Kojis and Quinn, 1984), however, in this particular study site a high coral recruitment rate was observed in spite of high sedimentation rates. The authors attributed the elevated recruitment rate to the presence of high coral cover and rich species diversity, the provision of large amounts of larvae from adjacent fecund reefs, and the high number of spawning acroporid corals.

Sediment particles in suspension also limit light availability for zooxanthellae photosynthesis. Coastal reefs are known to flourish at relatively high levels of sedimentation; however, they tend to be restricted to the upper 4-10 meters because reduced zooxanthella photosynthesis rates reduce growth at greater depths (Fabricius, 2011). Lower light levels at depths below 10 meters also inhibit the development of coral larvae by reducing the amount of energy made available to maturing embryos and ova. This was evident in a study which uncovered lower numbers of *Porites porites* larvae from colonies growing on reef ecosystems polluted by nutrient input and particulate matter in suspension, in comparison to the number of larvae sampled from a less polluted reef (Tomascik and Sander, 1987). Junjie et al. (2014) also found that due to the mechanical effects of sediment deposition, coral photosynthesis to respiration ratio (P/R ratio) and photosynthetic yield declined by as much as 21% and 18-34% for corals exposed to sediments, compared to corals in a shaded control environment which saw declines of only 14% and 3-17% (Junjie et al., 2014). In a simulation study carried out under laboratory controlled conditions, Humphrey et al. (2008) reported that coral fertilisation rates also decreased by more than 50% in correlation with increasing sedimentation rates of 100 mg L⁻¹ and decreasing salinity levels of 30 g L⁻¹. Moreover, there was a prevalence of development stage abnormalities in 100% of embryos and no fertilisation at a salinity concentration of 28 g L⁻¹. Gilmour (1999) also reported that in *Acropora digitifera*, a reef building coral species, suspended sediments of 50-100 mg L⁻¹ substantially reduced larvae survivability and settlement; along with significantly reduced fertilisation rates.

There is a general assumption that contemporary reefs located in nearshore light-limited environments are typically in poor health, with the availability of information on the

structure, community composition, and diversity of these shallow-water reefs remaining scarce due to the challenging field conditions present in these locales (Morgan et al., 2016). Recently, however, the persistence of reefs in areas characterised by low-light availability and periodic sediment smothering has been recognised, noting that coral reefs which grow and form in these settings can exhibit high live coral cover and species diversity (Gulliver et al., 2013, Sanders and Baron-Szabo, 2005). Furthermore, some reef corals have also evolved and adapted to high sediment-laden reef environments (Potts and Jacobs, 2000), and occur in various regions of the world (Anthony and Larcombe, 2000).

It is reported that the impact of these sediment induced conditions are not always negative, and that coral response to this stressor is species-specific (Sofonia and Anthony, 2008). The usual rates of sediment deposition on coral reefs are reportedly around $10 \text{ mg cm}^{-2} \text{ day}^{-1}$, between 10 and $50 \text{ mg cm}^{-2} \text{ day}^{-1}$ for reefs under moderate to severe sedimentation, and rates of $>50 \text{ mg cm}^{-2} \text{ day}^{-1}$ for reefs experiencing severe or catastrophic sedimentation (Birkeland, 1997, Rogers, 1990). For coastal reefs which are typically located in shallow depths, the sedimentary structure can be volumetrically dominated by silts and muds (Smithers and Larcombe, 2003), with the reef ecosystem largely susceptible to wind-driven sediment resuspension during storm events (Gulliver et al., 2013). The influx of Chromophoric Dissolved Organic Matter (CDOM) through sedimentation and sewage and river effluent material in near shore reefs brings about localised impacts to these ecosystems (Dupouy et al., 2014), however, it has been reported that CDOM lowered coral mortality as a result of bleaching in the Gulf of Kutch, Sri Lanka, through the absorption of ultra violet radiation considerably more strongly than particulates such as detritus, phytoplankton, and visible radiation (Jokiel and Brown, 2004). Despite nearshore contemporary reefs also being subject to nutrient stress as a result of inputs of poorly or inadequately treated sewage effluents into coastal waters, they are still capable of hosting high coral settlement, and diverse coral cover during these ongoing natural and anthropogenic perturbations (Lapointe et al., 2010).

The port city of Suva is the capital of Fiji and is considered the largest urban centre in the South Pacific, outside of Australia and New Zealand. Laucala Bay harbours the main large shipping port and most of the human settlements and industry of the region (Figure 1). Former larval recruitment studies in Suva Harbour were conducted offshore on the Suva

Reef, and within the deeper Suva lagoon (Quinn and Kojis, 2008, Vave, 2013), with no emphasis placed on particulate organic matter content and associated light penetration, or in-depth monthly monitoring of coral cover amidst sedimentation. A previous study led by Quinn and Kojis (2008) found that the lowest recruitment rate was observed at a sediment influenced site within Suva Harbour in the deeper lagoon, however, to date, no previous study has evaluated coral recruitment in close proximity to the industrial area despite the existence of several healthy coral assemblages. These include reef-building species from the genera *Acropora*, *Porites*, *Fungia* and *Pocillopora* which persist under constant environmental stress and in very close proximity to urban infrastructures. The site selected within Suva Harbour for this study receives high sedimentation input from the mouth of the nearby Tamavua River, consistently high freshwater influxes through storm water drains located along the city sea wall, and reported chemicals from agricultural runoffs, and sewage effluents from the adjacent Nabukalou Creek (Naidu and Morrison, 1994). The Suva Wharf, Walu Bay Industrial area, yachts berthed at the Royal Suva Yacht Club, and several nearby floating ship repair dry docks further contribute to the environmental stress experienced by the biota of Laucala Bay. The industrial activity has reportedly released toxic compounds such as lead and other heavy metals which would adversely affect the health of coral assemblages in the area (Prakash and Jokhan, 2013, Tabudravu et al., 2002). Furthermore, midway through this study (6th December 2014), a major sewage spill occurred in Suva Harbour, discharging about 200 ls⁻¹ of untreated waste water into Laucala Bay. This discharge continued unabated for 18 days, until temporary control measures were implemented leading to a Government Environmental Emergency Declaration prohibiting swimming and fishing in the affected waters. This study endeavoured to examine the impact of key pollution indicators on coral recruitment using a comparison between two representative inshore localities (Figure 1)

RESULTS

Monthly Sedimentation Rates. The Municipal Inshore Site, hereafter designated MIS, recorded the highest total monthly accumulated sediment weight (657.14 grams) after a monitoring duration of twelve months. Sediments retrieved from this site were found to be silt dominated due to close proximity to mangroves and a major river mouth. In the same period the Remote Inshore Site, hereafter designated RIS, recorded significantly less

sediment dry-weight (371.52 grams) ($U = 10733.5$, $p < 0.05$); Mann-Whitney U test). A two-way repeated measures ANOVA conducted after (log base 10 transformation) (including Within Subjects-Effects and Within Subjects-Contrasts) revealed a significant test statistic in terms of sediment dry-weight between sites ($F_{1,1} = 595.167$, $p < 0.01$). Further tests also revealed significant interactions ($p < 0.01$) between the factors (site and time). It was observed that after an initial high sediment dry weight value for the MIS at the start of the monitoring exercise in July 2014, a considerable decrease in sedimentation was noticed in this site in the subsequent four months (two bimonthly sampling intervals), followed by a peak in February 2015. The increase in sedimentation during this period coincided with the December 2014 sewage spill disaster in the Suva Harbour, which was presumed to be responsible for the increase in sedimentation seen during this period. A general decreasing trend in sedimentation was then observed until the conclusion of sedimentation monitoring in June 2015 (Figure 2). Average Daily Sediment Trap Collection Rates (ADCTR) recorded a significantly higher ADCTR in terms of sediment dry-weight ($U = 11296.5$, $p = 0.001$); Mann-Whitney U test) for the entire duration of monitoring in the MIS (Figure 3).

Particulate Organic Matter (POM). A statistically significant difference in the percentage of POM composition in sediment dry-weight was found between the MIS and the RIS for the duration of the study ($U = 8329.0$, $p < 0.01$; Mann-Whitney U test). This can be attributed to the amount of sedimentation influx, sewage release, and treated / raw black waters expected to be discharged in the MIS which is in very close proximity to one of the largest industrial areas in Fiji. Notably, it was observed that POM levels in the MIS were highly variable throughout the year (Figure 4).

Light Intensity. A One-Way ANOVA differences test confirmed a statistically significant difference in light intensity ($F_{3,1442} = 138.883$, $p < 0.01$) between different depth profiles between study sites (Table 1). Two depth profiles were measured at each site (see Methods). A Tukey HSD post-hoc test used to explore the multiple comparisons between the different depth profile groups found a highly significant interaction ($p < 0.01$), between the shallow depth profile in the MIS, and the shallow depth profile in the RIS, with a total mean difference of 167.5 lum/ft². There was also a highly significant interaction ($p < 0.01$), between the deep depth profile in the MIS, and the deep depth profile in the RIS, with a total mean

difference of 171.4 lum/ft². An Independent Samples t-test found a significant difference between the shallow and deep depth profile for the MIS ($F_{732,682}=11.452$, $p<0.01$), but not for the RIS ($F_{732,729} = 0.836$, $p>0.01$). Table 1, depicts differences in mean light intensity values recorded between similar depth profiles between study sites, with the MIS having the least light availability.

Photosynthetic Photon Flux Density (PPFD). A One-Way ANOVA test revealed a statistically significant difference ($F_{3,144}=128.804$, $p<0.01$), in PPFD calculated from light intensity data between different depth profiles between each study site (Table 2). A Tukey HSD post-hoc test used to explore multiple comparisons confirmed a highly significant interaction ($p< 0.01$), between the shallow depth profile in the MIS and the shallow depth profile in the RIS, with a total mean difference of $1.52 \text{ mol m}^{-2} \text{ d}^{-1}$. A significant interaction ($p<0.01$), between the deep depth profile in the MIS, and the deep depth profile in the RIS, was also found, along with a total mean difference of $1.48 \text{ mol m}^{-2} \text{ d}^{-1}$. An Independent Samples t-test found a significant difference between the shallow and deep depth profile for the MIS ($F_{732,648}=11.805$, $p<0.01$), but not for the RIS ($F_{733,732}=0.526$, $p>0.01$). A significantly higher mean PPFD was seen in the RIS compared to the MIS for both the shallow and deep depth profile category (Table 2).

Salinity and Dissolved Oxygen. Monthly mean salinity values between sites were found to be relatively similar, except for February 2015 and April 2015 in the MIS where a noteworthy reduction in salinity was recorded (27.50 ppt) and (27.50 ppt) respectively. Mean dissolved oxygen values between sites were found to be very similar between sites.

Coral Cover. For the MIS a statistically significant difference in mean ranks existed between the pair of observations for month 1 and 7 in terms of coral cover percentage ($p=0.043$; Wilcoxon's multiple comparisons post-hoc test). No statistically significant difference in mean ranks were found between month 1 and 12 ($p=0.500$), and month 7 and 12 ($p=0.686$). The RIS recorded a statistically significant difference in coral cover percentage between month 7 and 12 ($p=0.043$) and month 1 and 12 ($p=0.043$), with no significant difference found between months 1 and 7 ($p=0.144$).

A total of 15 coral species were identified in the MIS, compared to 14 species for the RIS in month 1, 11 species in the MIS and 13 species in the RIS in month 7, and 15 species in the MIS and 13 species in the RIS in month 12 (Table 3). In terms of species diversity between sites comparatively higher Shannon-Weaver Diversity Indices were recorded in the MIS for all monitoring months in relation to the RIS; Month 1: MIS-1.34, RIS-0.69; Month 7: MIS-1.30, RIS-0.68; Month 12: MIS-1.49, RIS-0.72.

For *Acropora* species present in both study sites, no statistically significant difference in the mean rank abundances of *Acropora elseyi*, *Acropora microphthalma*, *Acropora millepora*, *Acropora nobilis*, and *Acropora pulchra* was found to exist between the MIS and RIS ($p>0.05$; Mann-Whitney U test), except for *Acropora hyacinthus* where a higher mean rank abundance of this species was found in the RIS ($U= 82.50$, $p=0.035$, Mann-Whitney Test).

No statistically significant difference in the mean ranks of *Porites australiensis*, *Porites lobata*, and an unidentified *Porites* species existed between the MIS and RIS ($p>0.05$; Mann-Whitney U test), except for *Porites cylindrica* ($U= 45.00$, $p=0.001$), and *Porites rus* ($U= 47.50$, $p=0.007$) where higher mean rank abundances of these species were present in the RIS.

For an unidentified *Favites* species present in both sites, no statistically significant difference in mean rank abundances existed between the MIS and RIS ($U= 75.00$, $p=0.079$, Mann-Whitney Test). *Favites halicora*, however, exhibited a higher mean rank abundance in the RIS compared to the MIS ($U= 82.50$, $p=0.035$, Mann-Whitney Test). Similarly no statistically significant difference also existed in mean rank abundance for *Pocillopora damicornis* ($U= 90.00$, $p=0.073$, Mann-Whitney Test) and an unidentified *Pocillopora* species ($U= 99.00$, $p=0.490$, Mann-Whitney Test) present in both the MIS and RIS.

Miscellaneous species present in both the MIS and RIS did not record any statistically significant differences in mean rank abundances between sites; *Leptastrea purpurea* ($U= 99.00$, $p=0.490$, Mann-Whitney Test), *Fungia repanda* ($U= 90.00$, $p=0.073$, Mann-Whitney Test), *Platygyra sinensis* ($U= 95.50$, $p=0.313$, Mann-Whitney Test), *Pavona varians* ($U= 97.50$, $p=0.150$, Mann-Whitney Test), and *Psammocora* species ($U= 75.50$, $p=0.079$, Mann-Whitney Test).

Coral Recruitment. A total of 242 coral spat were discovered and positively identified from both study sites from July 2014 to July 2015, on a combined number of 144 terracotta settlement tiles. Two different sampling regimes to estimate coral recruitment were defined, Abundance (bimonthly) and Diversity (biannual) (see Methods). A subtotal of 110 spat were found from the coral spat “Abundance” category, compared to 132 spat recorded from the “Diversity” category. Interestingly, the MIS recorded a total coral spat density for the entire duration of the study which was not significantly different ($p=0.317$), from the total coral spat density found in the remote inshore site; MIS: 106 coral spat on a surface area of 6720cm^2 from 20 tiles, compared to 132 coral spat from the RIS on the same surface area and number of tiles. Four coral families were photographed and positively identified throughout the course of the study, namely: *Acroporidae*, *Pocilloporidae*, *Poritidae*, and *Mussidae*, with developmental stages from between two – six months for some families recorded and verified in accordance with Babcock et al. (2003). Coral spat retrieved from the MIS also demonstrated a cryptic settlement preference between corrugations present on the underside of settlement tiles.

In the bimonthly interval abundance sampling regime the MIS recorded 49 annual coral spat, compared to the RIS with 78 annual coral spat recorded. Table 4 displays the total abundance of coral spat families found between sites recorded in six bimonthly collection intervals. Coral spat from the Family *Mussidae* were notably absent from this sampling category, as this taxon was exclusively found in the six-monthly interval sampling regime. A significant difference in the abundance of Family *Poritidae* coral spat between the two study sites ($U=605.0$, $p=0.022$; Mann-Whitney U test) was found, with a higher abundance of this family found in the SIS. For all other coral families no significant difference in coral spat recruitment between sites was detected ($p>0.05$; Mann-Whitney U test).

In the coral spat biannual diversity sampling regime, 132 coral spat were found and identified from both study sites in the same period. A total of 87 spat were recorded at the MIS while the RIS recorded 83 coral spat. Table 5 displays the total abundance of coral spat families found between the study’s sites recorded in two biannual collection intervals. Coral spat from the Family *Mussidae* were exclusively found after six months of undisturbed artificial substrate availability. No statistically significant differences between study sites in

the abundance of coral spat from any Family were found ($p>0.05$; Mann-Whitney U test) suggesting that coral larvae indifferently settle in polluted and unpolluted environments.

DISCUSSION

Our results indicate that environmental stressors such as sedimentation and sewage pollution do not necessarily result in a reduction in coral cover, or a change in the recruitment rate of coral spat. Most field studies investigating the effects of sewage pollution on coral reef ecosystems have been short-term and limited in scope (Pastorok and Bilyard, 1985), and report that sewage-stressed ecosystems typically experience a decrease in coral cover, taxonomic richness, water clarity, larval recruitment, and decreased calcification rate as a result of the sewage effluent (Laws and Redalje, 1982). Conversely, our year-long recruitment study discovered that 106 coral spat successfully settled on artificial substrate (6720cm^2) in an environmentally stressed near-shore site, and in the midst of numerous anthropogenic stressor influences which are intrinsic to urban and industrial areas.

Corals are very vulnerable in their recruitment stage to stress as newly settled coral larvae and young colonies are extremely sensitive to adverse variables not conducive to their survival. In contrast to our results, very little coral larval settlement was observed taking place on sediment-covered surfaces in laboratory and field experiments (Hodgson, 1990, Te, 1992, Te, 2001), and also within the natural environment (DeMartini et al., 2013, Larcombe et al., 2001). Perez III et al. (2014) also report through laboratory experiments that larval recruitment is completely abated in sediment film environments below 0.9mg cm^{-2} (0.047 mm thick), and Quinn and Kojis (2008) revealed a total of 5 recruits per m^{-2} in a reportedly turbid site in Suva channel, Fiji. However, our results for Suva Harbour demonstrate that despite a total annual sediment yield of 657.14 grams for the stressed MIS, 106 coral spat per 6720cm^{-2} were found to settle in this site throughout this period. The RIS which experiences a lesser degree of anthropogenic disturbance presented with 132 recovered spat amidst a total annual sediment yield of 371.52 grams. The former finding was similar to results reported in Bauman et al. (2015), where periods of peak settlement was observed despite year round settlement, and through sustained anthropogenic disturbance (high sedimentation and turbidity). The peak in POM percentage in sediment dry-weight observed at the RIS from the month of March 2015 (0.75 grams) was likely attributed to increased phytoplankton

concentrations in the water column arising as a consequence of increased nutrient availability due to the December 2014 sewage spill disaster in Suva Harbour. The sole significant difference in the recruitment found in the abundance sampling regime for the *Poritidae* coral spat between the two study sites may imply a preference of habitat for this family as settling larvae in a highly disturbed equatorial reef were found to comprise only 6% of the total abundance, in comparison to other spat Families (Bauman et al., 2015).

We speculate that the influx of coral larvae is one of the more important factors influencing the persistence of the relic reef ecosystems found inshore. This could be possible through the seeding of coral larvae from nearby coral reef ecosystems, or through self-seeding which can be a primary factor in the resilience of isolated reef systems (Gilmour et al., 2009). Our findings also correlate with recent work undertaken by Bauman et al. (2015), and demonstrates that settlement patterns observed in the MIS are working to support sediment-tolerant local adult assemblages. In the bi-annual recruitment study, the absence of a statistically significant difference in the diversity of any particular coral spat family category between study sites highlights the resilience capacity of the MIS reef ecosystem in terms of a clear persistence in a sub-optimal environment. A clear demonstration of coral post-settlement survival is evident from our study. Family *Mussidae* spat demonstrated structural features indicative of six months of settlement i.e. two or more septal cycles along with the presence of a rudimentary columella, family *Poritidae* recruits exhibited large and typical adult corallite structures, along with *Pocilloporidae* recruits which displayed skeletal features typically seen at two months of development (Babcock et al., 2003).

Our observation that coral spat from the family *Mussidae* were exclusively found after six months of undisturbed artificial substrate availability substantiates the notion that there is a seasonal influence to the gametogenic cycle in this family. For example Soto and Weil (2016) found that oogenesis for the species *Isophyllia sinuosa* and *Isophyllia rigida* correlated with warm local sea surface temperatures. Our study, reports the presence of spats belonging to the family *Mussidae* only in December 2014 which is after the major coral spawning period for Fiji and throughout warm temperate seasonality.

It has been reported that the amount of available light intensity and spectral quality affects the settlement density, attachment position, and survival of coral larvae from zone-specific coral species in sub-tropical coral communities (Ho and Dai, 2014, Maida et al.,

1994, Mundy and Babcock, 1998, Minton et al., 2007). Despite this, our results for the MIS show an annual total of 49 coral spat recovered from six bi-monthly intervals in the abundance study throughout relatively low mean daily light compared to the RIS which recorded 78 annual coral spat for the same study with relatively higher mean daily light intensity Table 4.

We conclude that the MIS received sufficient daily PAR to allow the survivability of selected coral species since maximum photosynthesis rate in the zooxanthellae algal cells of *Pocillopora damicornis* and *Porites lobata* takes place at a light intensity (PPFD) of approximately ($200 \mu\text{mol m}^{-2} \text{s}^{-1}$ and about $350 \mu\text{mol m}^{-2} \text{s}^{-1}$) respectively and with other coral species also displaying photosynthetic efficiency in low light conditions (Kinzie III and Hunter, 1987, Riddle, 2013). It can also be assumed that light intensity is relatively restricted in the MIS due to sediment induced conditions and periodic incidences of sediment-resuspension as a likely result of consistent boat traffic originating from the Yacht Club and adjacent industrial area. It can also be inferred that light intensity in the RIS was also impaired as we found that the dominant coral species contributing to coral cover at the RIS was *Porites rus* which has a preference for turbid waters.

The reduction in salinity from 35-28 ppt is expected to significantly undermine successful coral fertilisation and also results in a 50% impairment in the development of active and motile swimming planulae larvae (Humphrey et al., 2008), with this event being a possible factor affecting larval recruitment in the MIS, as mean monthly salinity levels for February 2015 were (27.50 ppt), and April 2015 (27.50 ppt). These observed salinity levels may have been attributed to the heavy rainfall which occurred during the wet season period in the Fiji Islands for that year. Monthly mean dissolved oxygen values between the study's sites were also observed to be similar for the entire duration of monitoring, with no variation of this variable within the range of 4 Mg/L which would typically indicate severe macro-algal dominance (Haas et al., 2014).

The diverse coral cover and recruitment rate of viable coral spat seen in the MIS may be attributed to adaptation mechanisms, as some nearshore reef environments along the Great Barrier Reef coastline, Australia were reported to display high coral cover indicating adaption

to periodic stress events (Anthony and Larcombe, 2000). Possibly maximum sedimentation is only experienced in short periods which allows for potential recovery periods between sub-lethal sediment influxes, heterotrophy on suspended particles during reduced light levels and reduced rates of photosynthesis (Anthony and Larcombe, 2000, Browne, 2012, Rogers, 1983, Anthony and Fabricius, 2000), and photo acclimation by near shore corals in order to increase photosynthetic efficiency during incidences of high sedimentation. The adaptation of corals to varying sedimentation loads, short-term exposure to sedimentation, and reduced water quality throughout continuous coastal development has been readily documented (Browne, 2012, Rogers et al., 1984, Fisk and Harriott, 1989, Mwachireya et al., 2015), along with that of adult coral tolerance to eutrophic conditions and the ability to compete with macro algal populations (Fabricius, 2011). Rapid regrowth of remnant corals or asexual reproduction could also possibly play a significantly influential role in the maintenance of the local reef population in the MIS (Bauman et al., 2015), with cryptic settlement behaviour of spat also possibly contributing to post-settlement survival, and sediment load mitigation; as stated in Wham et al. (2017) where stress-tolerance characteristics of certain dinoflagellate species were reported.

Coral larvae may be attracted towards near-shore areas hosting diverse reef organisms for settlement, with settling coral larvae demonstrating positive responses to acoustic cues of a healthy reef consisting of fish calls and grunts, and that of snapping shrimps (Vermeij et al., 2010). The Suva Harbour municipal site is directly exposed to ranging magnitudes of noise pollution from large ships and small boats from the adjacent major Suva Port, floating dry-docks, the Suva Yacht Club, and drilling and construction noises from the nearby industrial area; with this modified acoustic environment possibly leading to the masking of important natural cues used by coral larvae as is the case in reef fish (Codarin et al., 2009, Slabbekoorn et al., 2010). More in-depth studies are required here in order to further evaluate and understand the correlations involved in this anomaly.

Despite this natural affinity towards healthy reef environments for settlement, coral larvae also display an indifference towards sediment polluted near-shore areas and are able to seek out suitable substrate by settling on high and low levels of sediment-covered surfaces in response to physical and algal-chemical cues (Tebben et al., 2015), and by using cilia to crawl along the sediment-covered substrate; essentially removing sediment and forming

tracks which are then used by other larvae for successful settlement (Perez III et al., 2014). Certain planulae larvae are also able to settle and survive in sedimented environments where other species would perish by relocating to alternative areas after settlement through reversible metamorphosis (Richmond, 1985). For example, it has been documented that larvae of *Pocillopora damicornis* are capable of retracting all tissue from the coral skeleton, reverting back to the planktonic form and resettling a second time if they are stressed within three days of settlement (Richmond, 1985).

While coral larvae settlement is influenced by physical parameters associated with reef surfaces (topography, colour, sound) and chemical cues (microbial biofilms, predator and prey odours, and algae); larval settlement and metamorphosis in response to these cues is selective in sub-optimal habitats (Tebben et al., 2015). It has been reported that in structurally complex, or low light environments, the detection of chemical cues and signals by aquatic organisms is impaired through the disruption of olfaction and chemosensory abilities (Leduc et al., 2004, Munday et al., 2009). This considerably affects homing, microhabitat selection, and the ability to perceive basic environmental stimuli (Leduc et al., 2013). Light variation and light colour is therefore an important cue used by coral larvae to discern depth and settlement surface orientation (Strader et al., 2015) and to identify optimum habitats for settlement and growth (Mundy and Babcock, 1998). For example a recent study suggests that artificial light prevalent in urbanised and developed coastal environments can both encourage and inhibit the settlement of coral larvae on hard surfaces in these near-shore areas (Davies et al., 2015).

The long-term evaluation of seasonal abundance and diversity of coral larvae, coral cover, sedimentation, light intensity, and temperature in close proximity to a major urban centre in Fiji and the Pacific region is previously absent. Previous recruitment studies undertaken in Suva Harbour have focused only on larval diversity through biannual settlement tile collections, and revealed comparatively lower recruitment farther offshore in Suva Channel and at a larger depth (Quinn and Kojis, 2008). Where larval abundance has been examined, monitoring duration is limited to six months and has been conducted offshore off the Suva Reef (Vave, 2013). This study discovered that consistent coral larval settlement rates were occurring in an area experiencing anthropogenic disturbances, a documented history of pollution (Naidu and Morrison, 1994), and high sedimentation, POM, and light

intensity levels. Our results indicate that coral larvae may not distinguish between study sites, however, further evidence which could be attained from extensive future studies are required to justify the findings of this study. The inclusion of offshore study sites may also serve to provide a stronger statistical comparison between site-results. The noteworthy anomalies in our findings should also be investigated through genetic analysis to test if the physiological tolerance observed is a plastic response from standing genetic diversity present beyond this relic reef or it is the consequence of local adaptation of a potentially strongly selected population. The adaptive responses of these corals to environmental stressors could then be analysed through translocation experiments.

MATERIALS AND METHODS

Coral Cover. A 2×2 meter portable quadrat was constructed from PVC pipes which were 20mm in diameter, with sections of PVC pipe drilled at 0.5 meter intervals in order to facilitate the forming of 16 sub-quadrats with lengths of nylon rope and numbered underwater tags. A camera tripod stand was also fabricated according to English et al. (1997) using welded ¼” iron rods along with an aluminium plate platform for camera placement. The tripod stand height ensured a distance of 60mm from the substrate, which deviated from the 80mm specification mentioned in English et al. (1997) in order to account for increased turbidity in the MIS.

Permanent quadrat establishment. Five permanent quadrats were established in each study site by deploying (four) 3/8” rebar iron markers into the substrate at each corner of the portable quadrat after placement on selected coral colonies. The top left hand marker of each permanent quadrat was affixed with an aluminium tag which was punched with holes specifying the particular quadrat number. In each study site Permanent Quadrat 1 was established in the shallowest depth, with successive permanent quadrats being established in incrementally deeper depths down the reef slope.

Data Collection. Laminated A4 sheet photographs displaying the correct orientation of the corners of each quadrat within quadrat markers were also used as an underwater guide to

ensure correct placement of the portable quadrat within the quadrat markers. An Olympus Tough TG2 underwater digital camera with an attached FCON-T01 Fisheye Converter lens was placed atop of the camera platform of the tripod stand, with the tripod stand then placed exactly atop of each sub quadrat and photographed in a left-right direction until all 16 sub-quadrats were photographed. Sampling could not be undertaken in both study sites for the period spanning December 2014 – January 2015 due to a national environmental disaster which had arisen due to a major sewage spill disaster in the Suva harbour area on December 6, 2014. Monitoring was resumed at the earliest allowable opportunity, which was in February 2015.

Image processing. Coral Point Count with Excel extensions (CPCe v.4.1) software was used to analyse coral cover statistics in relation to other major categories e.g. macro algae, sand etc., as well as coral species abundance and diversity. Each sub-quadrat image was calibrated to scale (50cm×50cm) and then overlaid with 20 software-generated random points; with the life form features underlying each point subsequently identified. Processed sub-quadrat photos were then collectively analysed for coral cover, and coral species diversity and abundance for each quadrat. Despite data having been collected for every month, only data recovered every six months was analysed and used to compare differences in coral cover and species diversity and abundance; in accordance with standard ecological monitoring practices (Hill and Wilkinson, 2004).

Coral Recruitment. Terracotta tiles used for spat collection (12cm × 12cm ⁵¹) were affixed to a recruitment station rack (RSR) constructed using sections of welded wire mesh which were bent at a general 90° angle, with an allowable spacing of at least 2.0 cm between each tile. Terracotta tiles chosen for this study were unglazed and had corrugations present on the underside. Each study site had five racks permanently secured to the ocean floor with U-shaped hooks, with one rack deployed alongside a permanent quadrat. At both study sites, RSR's were strategically deployed in order to ensure the placing of the stations in gradually increasing depth profiles from shallowest (1.6 m) to deepest (2.1 m).

Coral abundance and diversity. Tiles from racks allocated to the second and fourth quadrats at each site were assigned for the monitoring of the abundance of coral larval families for the duration of the entire study and these were consecutively sampled every two

months, with the tiles rotated with fresh ones. Tiles from racks allocated to the first, third and fifth quadrats at each study site were assigned to monitor the diversity of planulae larvae undergoing settlement and establishment on a six-monthly basis. Predicted mass coral spawning dates for Fiji in 2014 were determined in accordance with Mildner (1991), and found to occur between October 14th and November 13th. Settlement tiles were established one month before the commencement of spawning, with tile retrieval conducted at least within one month after spawning.

Settlement tile retrieval and recovery process. Settlement tiles were retrieved using custom-made wooden trays in order to minimize damage to settled spat during transport to the laboratory. Retrieved tiles were washed in running freshwater to remove sediments and algae; the cleaned tiles were then placed in labelled stainless steel trays filled with a 10% diluted bleach solution (CLOROX™, 8.25% Sodium Hypochlorite) until the tiles were completely immersed and left to stand for 24 hours in order to remove organic material to reveal diagnostic skeletal features. Tiles were then washed with freshwater and allowed to dry at room temperature before being searched twice for coral spat in accordance with the protocol developed by Harriott (1992).

Coral spat search and identification. An OLYMPUS™ SZ51 binocular microscope was used to detect coral spat on recovered tiles; each visible surface being searched at the lowest magnification setting (0.8X) in a “zigzag” fashion as demonstrated by Vave (2013), with the aid of a miniature fluorescent desktop lamp as the primary source of illumination. Corrugations present on the underside of the tile were intensively searched, and where applicable a small steel spatula was used to remove calcareous or organic matter in order to expose the underlying tile surface in an attempt to locate coral spat. Upon discovery of coral spat, the magnification was then increased to 4X and the spat identified to Family level based on skeletal structural features using the taxonomical method of Babcock et al. (2003), as implemented in Vave (2013). Spat which could not be distinctly identified due to insufficient skeletal growth or due to damage to the corallite skeleton were grouped into an “Unidentifiable” category.

Settlement tile surface area and total coral spat density. The shape of each identical square tile was taken as a right rectangular prism of sides equal to 12 cm and height 1 cm, with a fixed volume of 144 cm³. The surface area of each tile was therefore calculated using

the formula: $A = 2(wl + hl + hw)$ giving a total surface area for individual tiles of 336 cm². Total surface area relating to each spat count observation in each study site was calculated in order to make a correlation with total coral spat density for a fixed area, and during a given period of time.

Sediment Analysis. Sediment traps were constructed according to guidelines recommended in English et al. (1997). One sediment trap was deployed alongside each of the five permanent quadrats in each of the two study sites. Each sediment trap consisted of three identical PVC pipes (50 mm in diameter and 115 mm long) adjacent to each other, with sealed bases, and affixed with cable ties onto a rebar construction rod 1.50 meters long. No baffles were placed at the mouth of PVC traps used in this study as it was deemed that their use may result in decreased trapping efficiency (Knauer and Asper, 1989). The base of each PVC trap was sealed using a specially adapted PVC pipe cap, and cemented with PVC solution to ensure permanent adhesion.

Study site field data collection. Sediment traps were collected on a monthly basis from the date of establishment, for a period of twelve months.

Laboratory Analysis. Following retrieval, the entire contents of each PVC trap was transferred directly into clean 50mL Eppendorf centrifuge tubes using a clean metal spatula. Distilled water was used to aid in the removal of the sediment sample from the PVC trap, and also to fill each tube up to the 50 mL mark. Algal growth and encrusting matter found along the inside of each trap was not collected for analysis, however, distilled water was used to thoroughly flush and retrieve any ensnared sediment matter from these growths in order to ensure unbiased determination of particulate organic matter (POM). Each sample was centrifuged for 10 minutes at 4,500 rpm and 26 °C in a refrigerated centrifuge (Thermo IEC Centra CL3R). The supernatant was then poured off and the centrifuge tube filled to the 30mL mark with distilled water. The tube was then shaken to stir the contents, and re-centrifuged at 4,500 rpm for a further 10 minutes. This was done in order to ensure the removal of magnesium and calcium carbonate salts from the remaining sediment pellet.

Sediment net Dry Weight. Following centrifugation, the supernatant was discarded, and the sediment pellet transferred using a spatula and distilled water to a pre-weighed ceramic crucible pre-conditioned in a muffle furnace (Ceramic Engineering OELMEC) for 4 hours at 450°C. Once removed from the muffle furnace the crucibles were immediately allowed to

cool in a desiccator for 30-40 minutes. Once cooled, the crucibles were placed collectively in a tray, and placed in a drying oven (OSK 9519A) for 12-14 hours at 60°C, or until a constant weight was achieved for individual crucibles containing the sediment pellets. The crucibles were then removed from the drying oven and placed immediately to cool in a desiccator for a further 30-40 minutes. The individual crucibles with pellets were then weighed and the net weight (in g.cm⁻²) of the pellets recorded.

Particulate Organic Matter (POM). Following net pellet weight determination, the crucibles with sediment pellets were again placed into the muffle furnace for 4 hours at 450°C for ashing. The heated crucibles were then allowed to cool for 360 minutes within the furnace and subsequently transferred to a desiccator to allow for further cooling to ambient temperature. The crucibles were then re-weighed and the net Ashed Weight in grams recorded after correction for crucible weight. Ash-Free Dry Weight (AFDW) was calculated using the difference between the dry-weight and the ashed weight, which is equivalent to the organic particulate matter content (POM) and expressed as a percentage of the total dry weight.

Average Daily Sediment Trap Collection Rates. The average daily sediment trap collection rate in grams per day was calculated for each PVC pipe trap by dividing the total dry-weight mass of sediments in each trap by the cross-sectional area (cm²) of the trap mouth, and further dividing this figure by the number of days the particular trap was deployed in the study site (DeMartini et al., 2013, Storlazzi et al., 2011). The cross-sectional area of each sediment trap mouth was calculated using the formula: $A = \pi r^2$, and for a trap mouth diameter of 5 centimeters, the cross-sectional area was 19.625 cm².

Light Intensity and Temperature. Six Temperature and Light Data Loggers (HOBO® Pendant®, model UA-002-64) were used to monitor these parameters at ten-minute intervals twenty four-hours daily, and for monthly logging periods throughout the 12-month study. Data loggers were placed in pairs at each site in equidistant positions. In order to acquire an accurate representation of temperature and light intensity variation with depth at each study site, one logger in each study site was deployed in the shallow depth (Depth 1), with the other logger deployed in the deep depth (Depth 2).

In order to allow for the identification and removal of extreme outliers in the dataset, and the acquisition of accurate values for daily mean, daily maximum, daily sum for light

intensity, Photosynthetic Photon Flux Density (PPFD), and temperature; data was downloaded using the HOBO® BASE-U-1 station in Excel format, and monthly data for both variables comprising of cumulative daily values were plotted in the form of Box and Whisker plots using a statistical package (Software Package for Statistical Analysis (SPSS) v. 21)

Salinity and Dissolved Oxygen. Salinity, Conductivity and Dissolved Oxygen, was measured at each site monthly using a YSI-85 multi-parameter probe. The equipment was first calibrated in terms of the correct height at sea level, with three measurements for each parameter then undertaken at varying depths: 0.3 meters, 1.5 meters, and 2.5 meters. Mean values were then derived from these successive measurements.

Statistical Analysis. All categories of data in this study, other than that of light intensity and PPFD, did not fulfil the conditions of normality and homoscedasticity, and were therefore analysed using non-parametric statistical tests in SPSS (v.21). For the coral spat family abundance and diversity categories, a differences analysis using the Mann-Whitney U test was conducted. In order to explore statistically significant associations between coral spat family abundances and diversity found in study sites and seasonality, and also for the zero coral spat count prospective cohort study, the Pearson's Chi Squared test was employed. To investigate for the presence of significant differences between study sites for sediment dry-weight, particulate organic matter, and average daily sediment trap collection rates, the Mann-Whitney U test was again performed. A parametric One-Way ANOVA differences test was used to investigate for the presence of any significant differences in light intensity between different depth profiles between and within study sites, with the Tukey HSD (Honestly Significant Difference) post-hoc test being further employed in order to explore multiple comparisons between the different depth profile groups between and within study sites.

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Author contributions

R.L., R.H.R. and A.D.R.N.Y. designed the study, R.L. and R.H.R. established the study sites, R.L. and C.R. performed the sample collections, R.L. carried out experiments and conducted analyses, R.L., C.R., S.K. and A.D.R.N.Y. wrote the manuscript; and all authors read and approved the manuscript.

Competing financial interests

The authors declare no competing financial interests

Table 1: One-Way ANOVA test results and daily mean light intensity values recorded annually between sites at similar depth profiles; Site 1: Municipal Inshore Site, Site 2: Remote Inshore Site; Depth 1: Shallow, Depth 2: Deep

| Site and depth profiles | Total Light Intensity Mean (lum/ft ²) | Significance value (interaction between groups) |
|-------------------------|---|---|
| Site 1 Depth 1 | 5821.34 ± 5.69 | 0.000 |
| Site 1 Depth 2 | 3941.04 ± 4.53 | |
| Site 2 Depth 1 | 18065.37 ± 10.19 | |
| Site 2 Depth 2 | 17196.56 ± 10.75 | |

Table 2: One-Way ANOVA test results and daily mean PPFD values recorded annually between sites at similar depth profiles; Site 1: Municipal Inshore Site, Site 2: Remote Inshore Site; Depth 1: Shallow, Depth 2: Deep

| Site and depth profiles | Daily PPFD Mean (mol m ⁻² d ⁻¹) | Significance value (interaction between groups) |
|-------------------------|--|---|
| Site 1 Depth 1 | 0.64 ± 0.05 | 0.000 |
| Site 1 Depth 2 | 0.48 ± 0.03 | |
| Site 2 Depth 1 | 2.16 ± 0.09 | |
| Site 2 Depth 2 | 1.96 ± 0.09 | |

Table 3: Coral species percentages of monthly coral cover

| Coral species | Site and monthly abundance (mean % of Coral Cover) | | | | | |
|-------------------------------|--|-------|---------|-------|----------|-------|
| | Month 1 | | Month 7 | | Month 12 | |
| | MIS | RIS | MIS | RIS | MIS | RIS |
| <i>Acropora elseyi</i> | 1.86 | 0.38 | 1.09 | 0.32 | 0.82 | 0.31 |
| <i>Acropora hyacinthus</i> | 0 | 0.25 | 0 | 0.25 | 0 | 0.25 |
| <i>Acropora micropthalma</i> | 1.51 | 2.90 | 2.88 | 2.59 | 1.52 | 2.64 |
| <i>Acropora millepora</i> | 3.73 | 0 | 0 | 0 | 0.64 | 0 |
| <i>Acropora nobilis</i> | 6.12 | 0.76 | 0.76 | 0.57 | 0.71 | 0 |
| <i>Acropora pulchra</i> | 0.20 | 0 | 0.63 | 0 | 0 | 0 |
| <i>Favites sp.</i> | 0.07 | 0 | 0 | 0 | 0.13 | 0 |
| <i>Favites halicora</i> | 0 | 0.25 | 0 | 0 | 0.13 | 0 |
| <i>Fungia repanda</i> | 1.77 | 0.19 | 2.66 | 0.38 | 2.21 | 0.44 |
| <i>Leptastrea purpurea</i> | 0 | 0.90 | 0.76 | 0 | 0.96 | 0.06 |
| <i>Millepora tenella</i> | 0 | 13.42 | 0 | 12.13 | 0 | 10.53 |
| <i>Porites australiensis</i> | 0 | 0 | 0 | 0.06 | 0 | 0.44 |
| <i>Porites cylindrica</i> | 0 | 2.83 | 0 | 2.21 | 0 | 2.08 |
| <i>Pocillopora damicornis</i> | 2.05 | 0.56 | 1.91 | 0.19 | 2.67 | 0.38 |
| <i>Porites lobata</i> | 5.39 | 15.03 | 6.40 | 14.39 | 15.14 | 5.71 |
| <i>Pocillopora</i> | 0.07 | 0 | 0 | 0 | 0 | 0 |
| <i>Porites sp.</i> | 0.52 | 0 | 0 | 0 | 0 | 0 |
| <i>Porites rus</i> | 2.19 | 31.57 | 1.72 | 29.57 | 0.82 | 23.46 |
| <i>Platygyra sinensis</i> | 0 | 0.06 | 1.72 | 0.06 | 0.06 | 0.25 |
| <i>Psammocora sp.</i> | 0.07 | 0 | 0 | 0.06 | 0.13 | 0.13 |
| <i>Pavona varians</i> | 0.13 | 0 | 0 | 0 | 0.25 | 0 |
| <i>Stylophora pistillata</i> | 0.39 | 0 | 1.39 | 0 | 1.70 | 0 |
| <i>Turbinaria reniformis</i> | 0 | 0.13 | 0 | 0 | 0 | 0 |

Table 4: Total coral spat numbers from six bimonthly “Abundance” collection intervals; MIS: Municipal Inshore Site; RIS: Remote Inshore Site

| Coral spat Family | Coral spat sum in sites | | Mann-Whitney Mean Ranks | |
|-----------------------|-------------------------|-----------|-------------------------|-------|
| | MIS (Sum) | RIS (Sum) | MIS | RIS |
| <i>Acroporidae</i> | 3 | 3 | 40.50 | 40.50 |
| <i>Pocilloporidae</i> | 31 | 28 | 39.61 | 41.39 |
| <i>Poritidae</i> | 33 | 12 | 35.63 | 45.38 |
| <i>Mussidae</i> | 0 | 0 | 38.85 | 42.15 |
| <i>Unidentifiable</i> | 11 | 6 | 40.50 | 40.50 |

Table 5: Total coral spat numbers from two biannual “Diversity” collection intervals; MIS: Municipal Inshore Site; RIS: Remote Inshore Site

| Coral spat Family | Coral spat sum in sites | | Mann-Whitney Mean Ranks | |
|-----------------------|-------------------------|-----------|-------------------------|-------|
| | MIS (Sum) | RIS (Sum) | MIS | RIS |
| <i>Acroporidae</i> | 9 | 28 | 21.88 | 27.13 |
| <i>Pocilloporidae</i> | 31 | 9 | 25.27 | 23.73 |
| <i>Poritidae</i> | 20 | 11 | 26.50 | 22.50 |
| <i>Mussidae</i> | 3 | 5 | 23.94 | 25.06 |
| <i>Unidentifiable</i> | 24 | 14 | 26.96 | 22.04 |

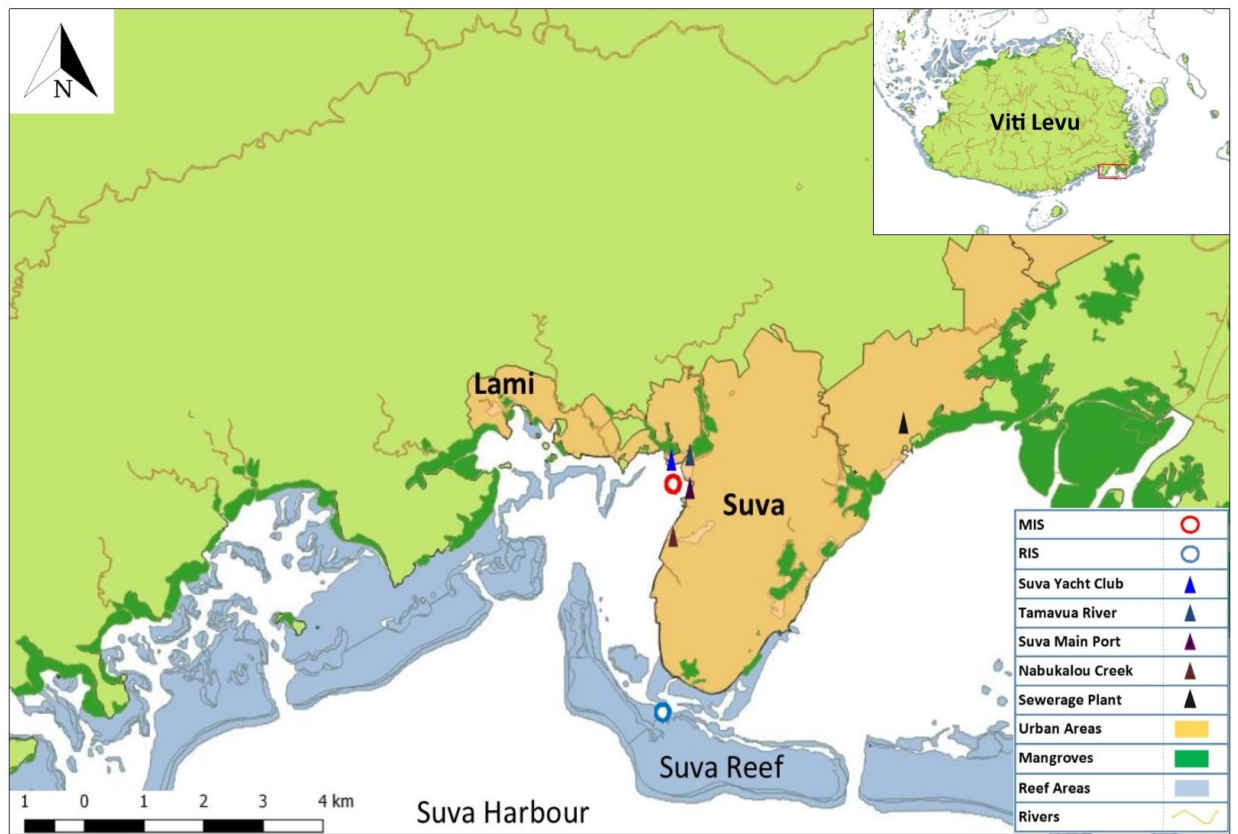


Fig 1: Site map showing study areas in the island of Viti Levu, Republic of Fiji.

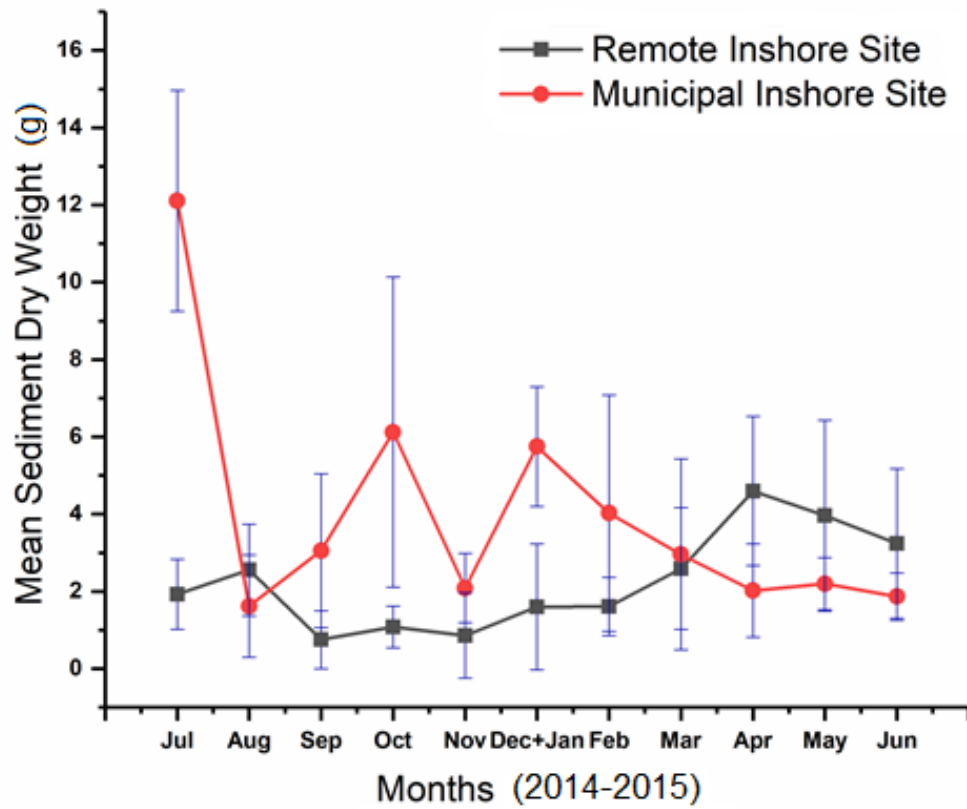


Figure 2: Mean sediment dry-weight between study sites

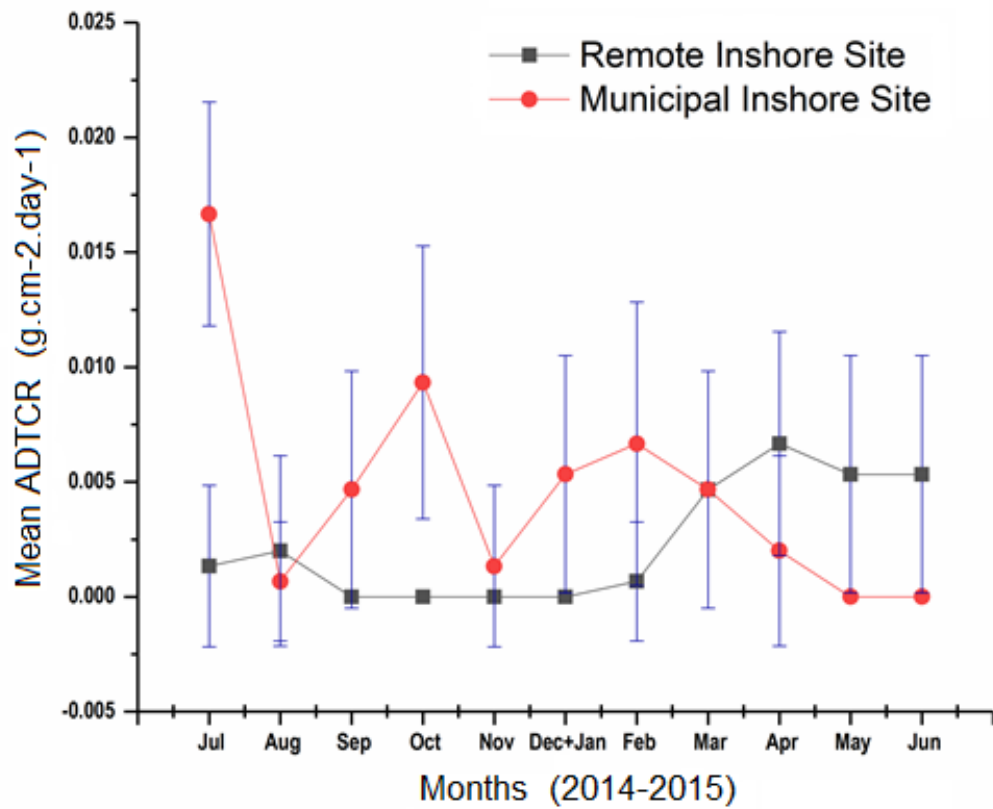


Figure 3: Mean Average Daily Trap Collection Rate in terms of sediment dry-weight between study sites (± 2 SE)

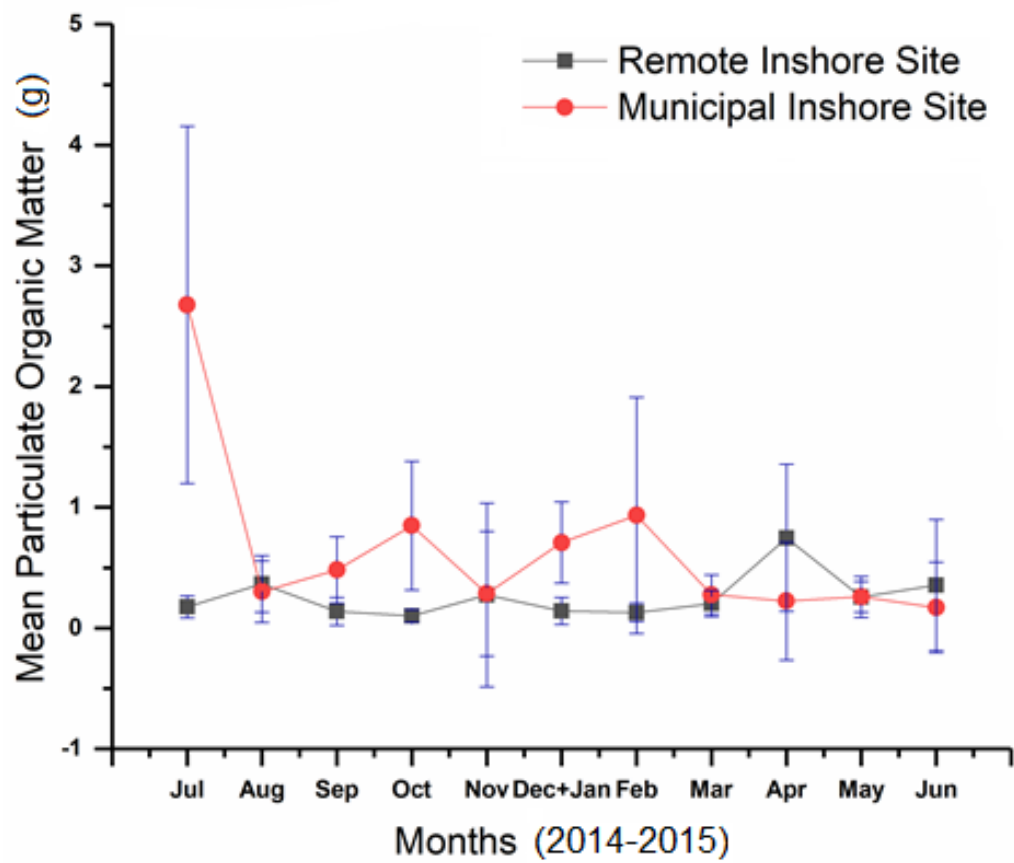


Figure 4: Mean Particulate Organic Matter between study sites

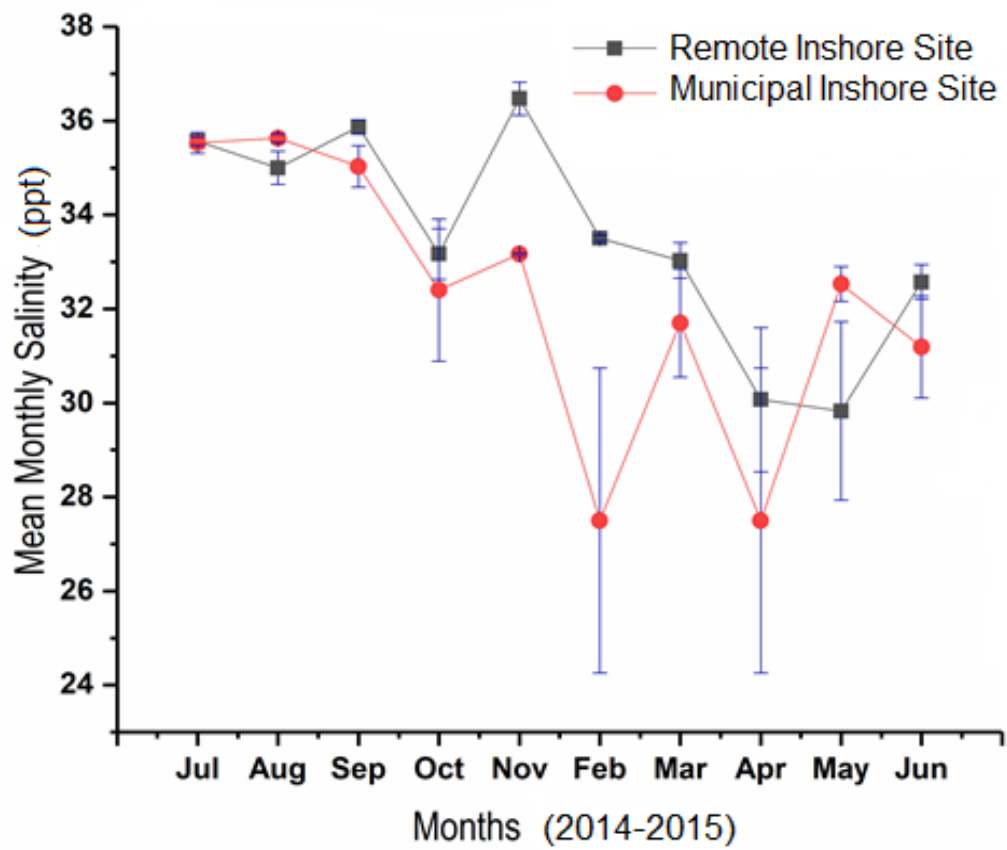


Figure 5: Mean Monthly Salinity between study sites

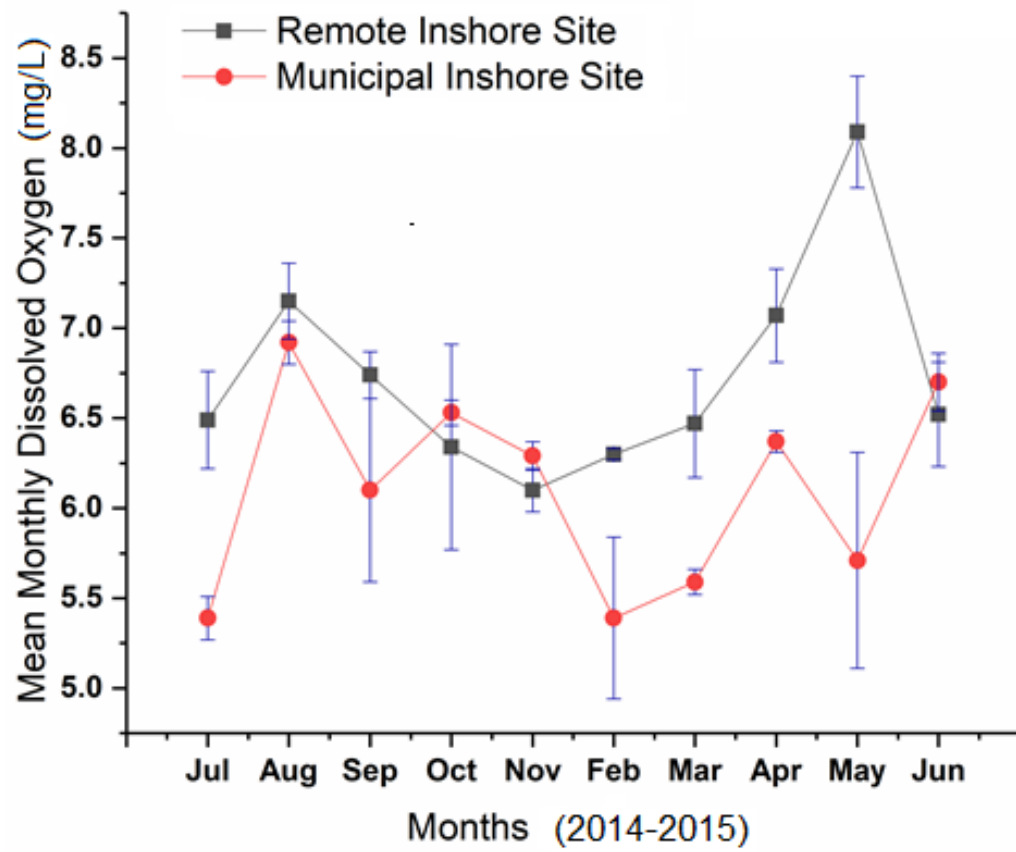


Figure 6: Mean Monthly Dissolved Oxygen between study sites

Supplementary Information

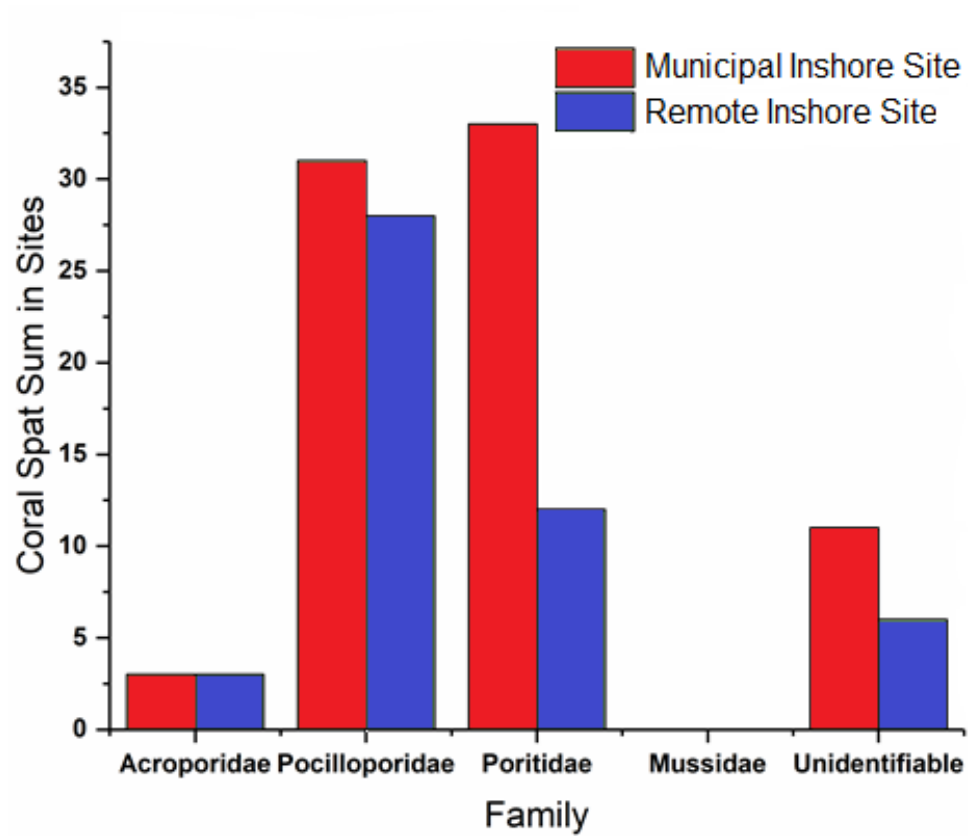


Figure 7: Coral spat abundance

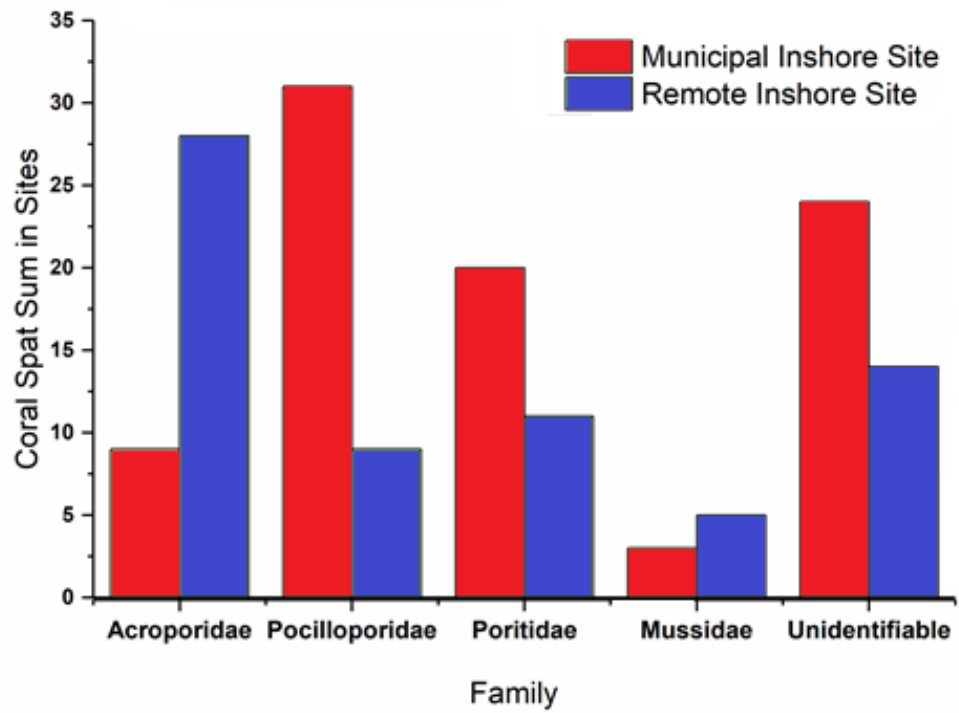


Figure 8: Coral Spat Diversity

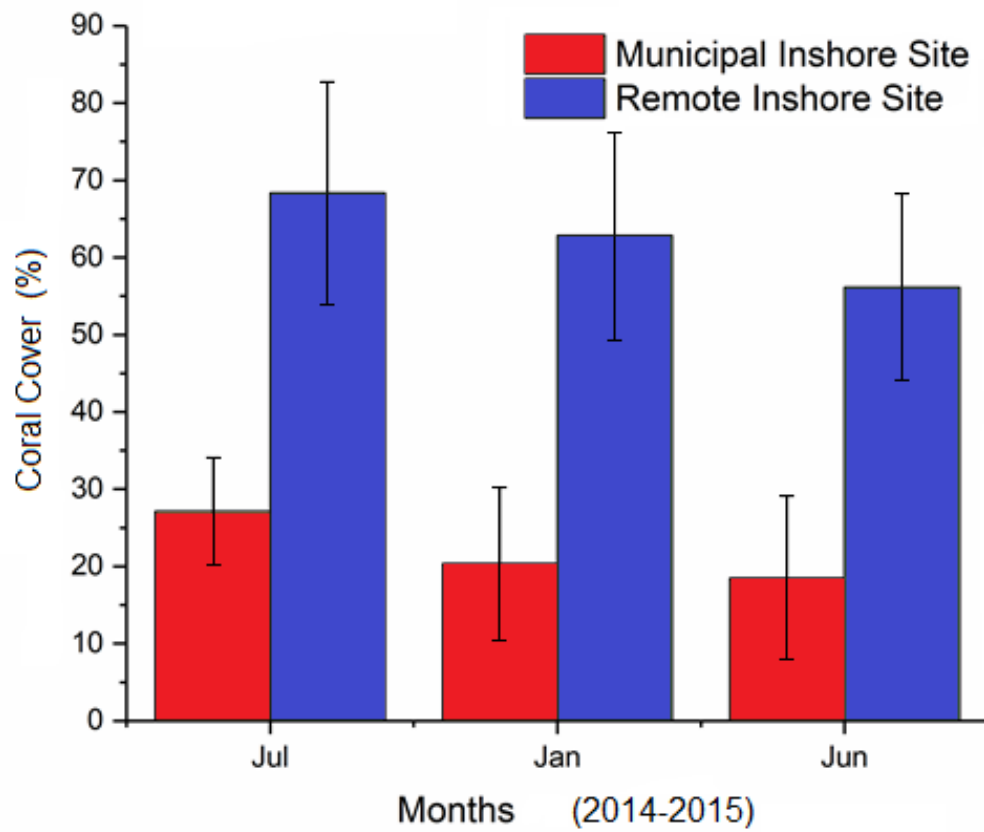


Figure 9: Coral cover

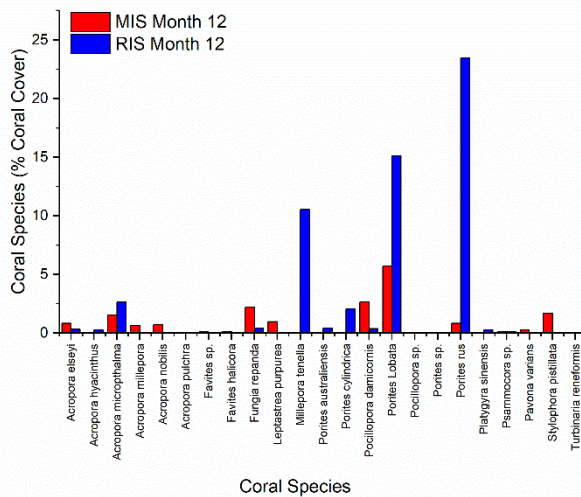
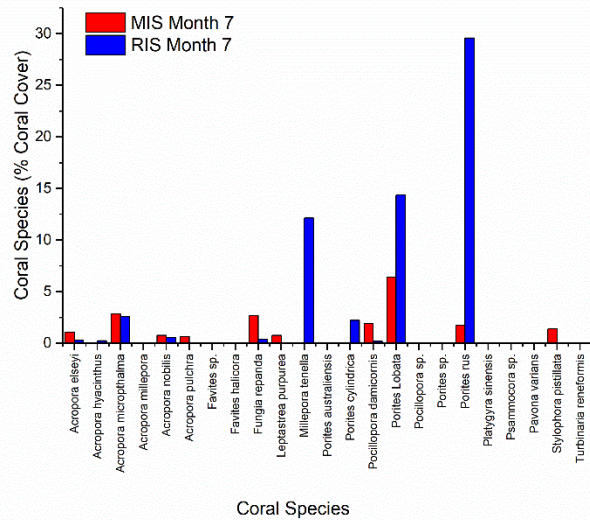
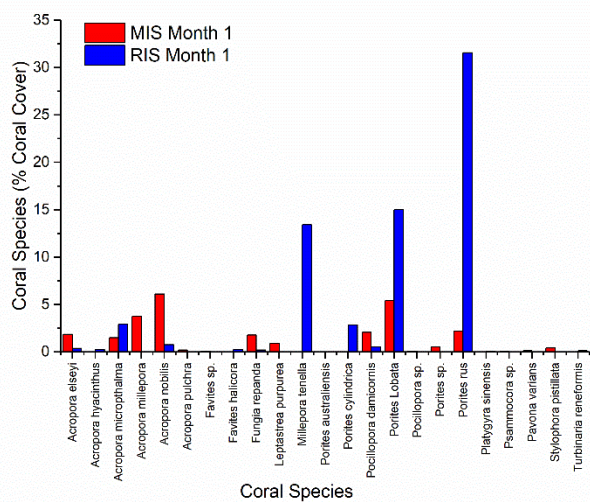


Figure 10: Coral cover species diversity (Month 1; Month 7; Month 12)

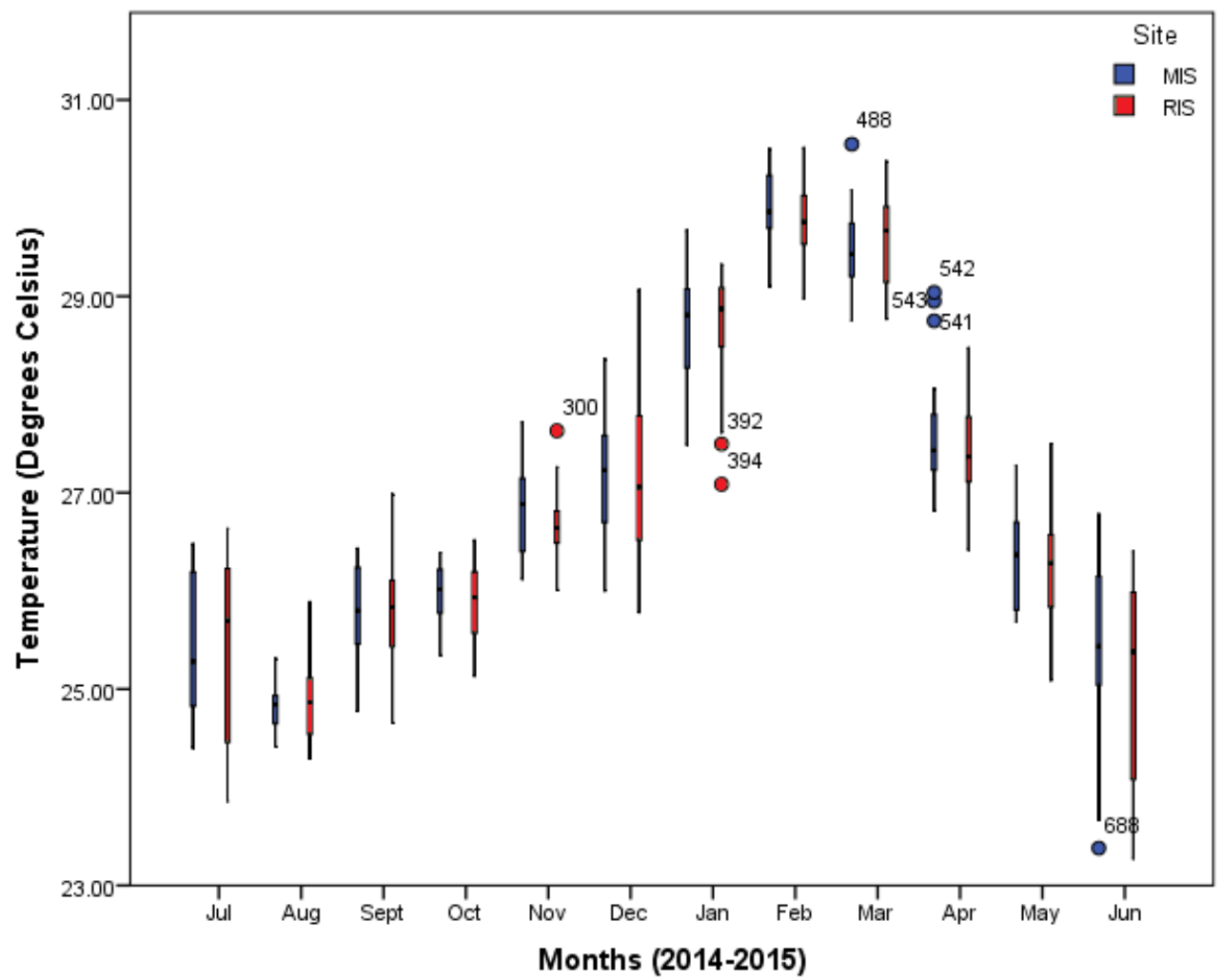


Figure 11: Mean temperature between sites (Shallow Depth)

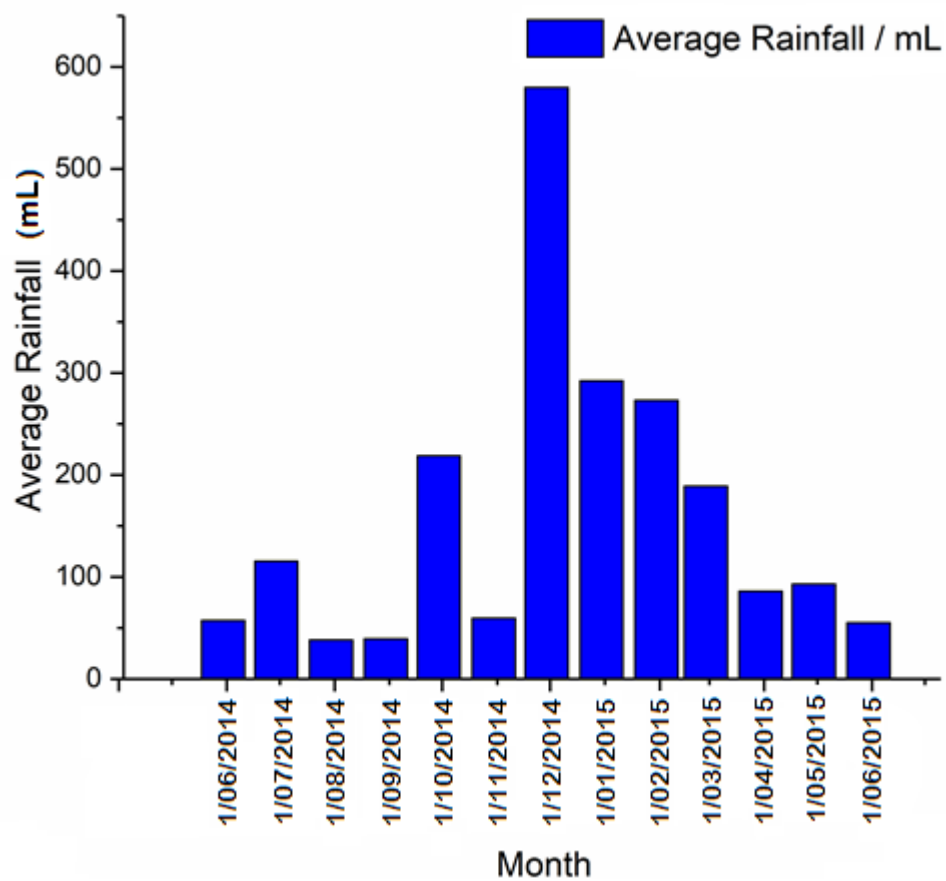


Figure 12: Average monthly rainfall: Laucala Bay, Fiji (June 2014 - June 2015).
Data provided by THE FIJI METEOROLOGICAL SERVICE OFFICE (Data Request
Reference No. MET 49/2)

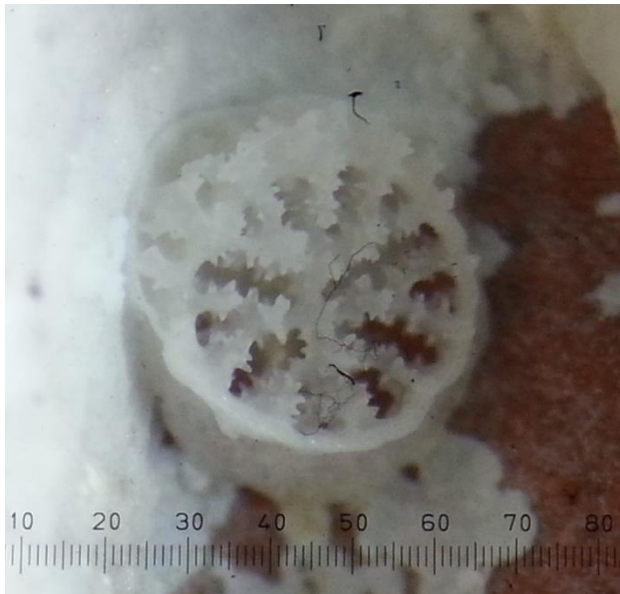


Figure 13: Coral spat photomicrographs: top-left: Poritidae; top-right: Mussidae; bottom-left: Pocilloporidae; bottom-right: Acroporidae



Figure 14: Frontal view of settlement tiles: MIS. Collected 24/11/14

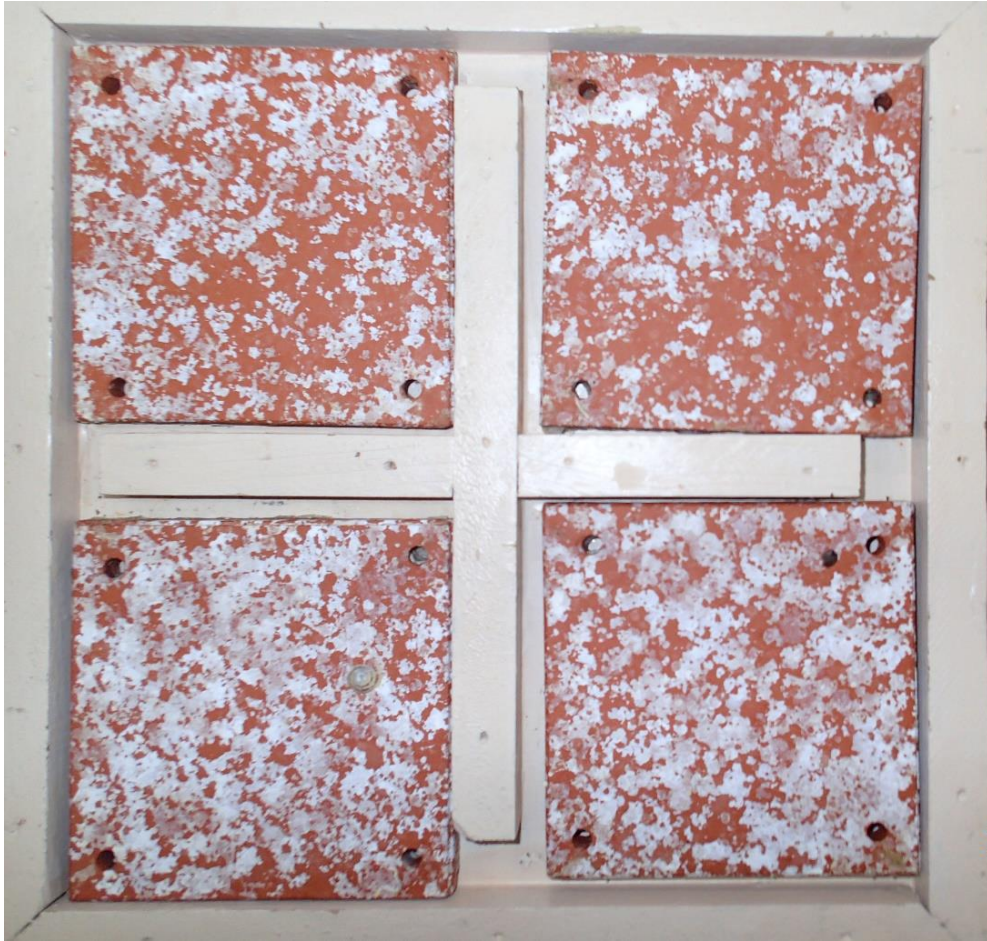


Figure 15: Frontal view of settlement tiles: RIS. Collected 13/11/14